Report from the Neutrino Physics Driver Group

October 7, 2015

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Our Science Driver

Pursue the physics associated with neutrino mass

Propelled by surprising discoveries from a series of pioneering experiments, neutrino physics has progressed dramatically over the past two decades. A diverse research program exploiting particle astrophysics, accelerator and reactor experiments has uncovered a new landscape in neutrino physics, with a promising future for continued discovery. Recent results indicate that answers to some of the most significant questions about neutrinos lie within reach of the next generation of experiments. Physicists now know that neutrinos exist in three types and that they oscillate, *i.e.*, they change type as they move in space and time. The observed oscillations imply that neutrinos have masses. Many aspects of neutrino physics are puzzling, and the experimental picture is incomplete. Powerful new facilities are needed to move forward, addressing the questions: What is the origin of neutrino mass? How are the masses ordered (referred to as mass hierarchy)? What are the masses? Do neutrinos and antineutrinos oscillate differently? Are there additional neutrino types or interactions? Are neutrinos their own antiparticles?

Parallel Session Talks

What new technologies are needed to move forward?

14:00 **New Technologies for Neutrino Oscillations** *45'*
Speaker: Jonathan Asaadi (Syracuse University)
Material: Slides

14:45 **New Technologies for Neutrino Interactions** *45'*
Speaker: Ornella Palamara (Fermilab)
Material: Slides

15:30 **Coffee Break** *30'*

16:00 **New Technologies for Neutrino Astrophysics** *45'*
Speaker: Joshua Klein (Penn)
Material: Slides

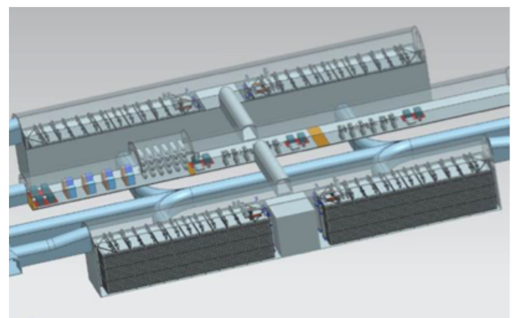
16:45 **New Technologies for Neutrino Properties** *45'*
Speaker: Phil Barbeau (Duke)
Material: Slides

many overlaps between these (and with DM)

+ many talks in technology parallels

Findings: Neutrino Oscillations

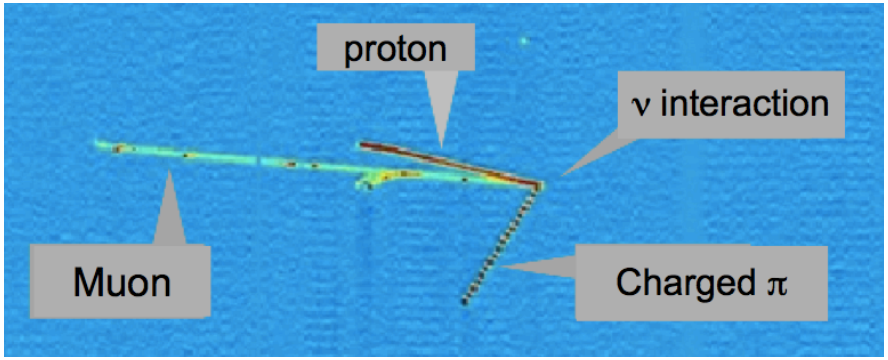
- The community is preparing for long- and short-baseline neutrino experiments, mostly **LArTPC-based** in the US
- **DUNE** is a key activity
  - Still very **many challenges**: HV, photons, reconstruction of final states
  - Dual vs single phase
  - Technical synergies with the short-baseline LAr program



- Some US interest in other oscillation programs as well
  - Sterile neutrinos at reactors, source experiments, water, WbLS, ...
- [Development of new neutrino sources of interest as well
  - high-power DIF beams, cyclotrons, IsoDAR (but not in our purview)]

Findings: Neutrino Interactions

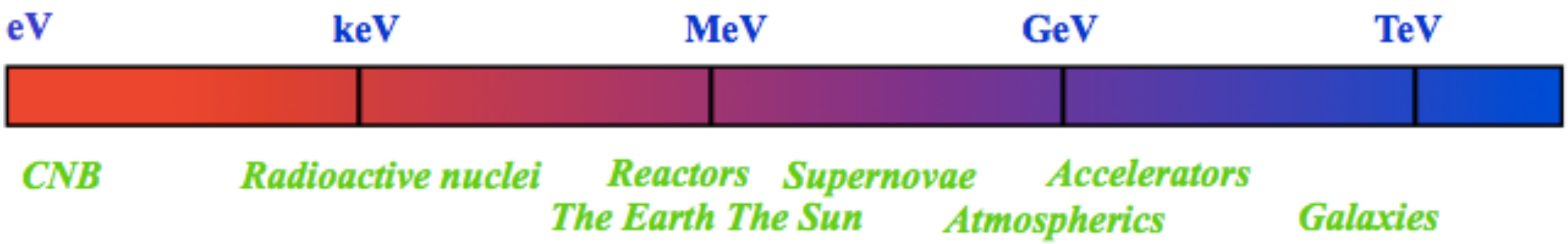
- Detailed understanding of neutrino interactions, especially in the ~few GeV regime, is **critical** for interpretation of neutrino oscillation experiments (**dominant systematic**)
  - Similar technology challenges as for oscillations, but need dedicated measurements ➔several underway, some new ideas



- Understanding of neutrino interactions in the ~tens of MeV regime also important for interpretation of supernova neutrinos
  - no near-term plans for LAr measurements

Findings: Neutrino Astrophysics

- Still interesting physics in atmospheric, solar, supernova, relic supernova, geo, UHE, cosmic background, spanning many orders of magnitude in energy
- Particle physics as well as astrophysics (e.g., oscillations)

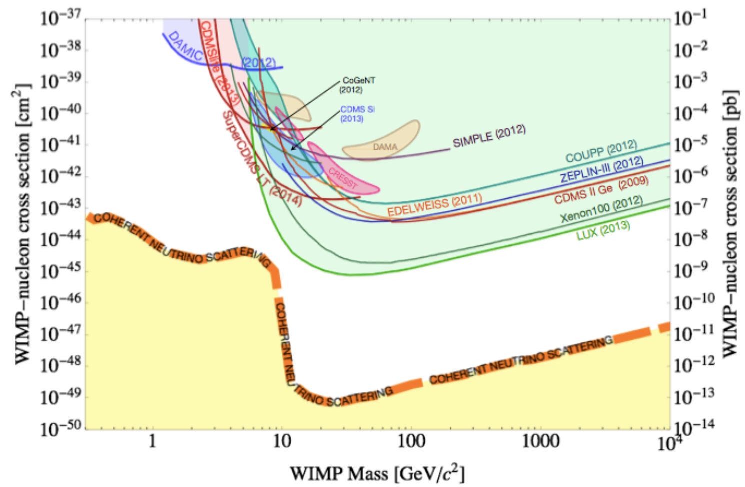


- Diverse technologies; for many topics, use large homogeneous detectors (scintillator, water, noble liquid)
- Limited primarily by cost for **mass** and **photosensors**

Findings: Neutrino Properties

- Neutrino absolute mass: KATRIN uses MAC-E filter, new ideas w/ Ho-163 and cyclotron radiation emission spectroscopy (NP stewarded?)
- **Neutrinoless double beta decay: unique way of getting at the fundamental Majorana-vs-Dirac question**
  - In principle NP-stewarded going forward but still great interest and technical expertise within HEP community
  - multiple approaches, daunting background requirements
- Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) is background for DM, and signal in itself
- Neutrino magnetic moment also interesting

large, low-threshold detectors required

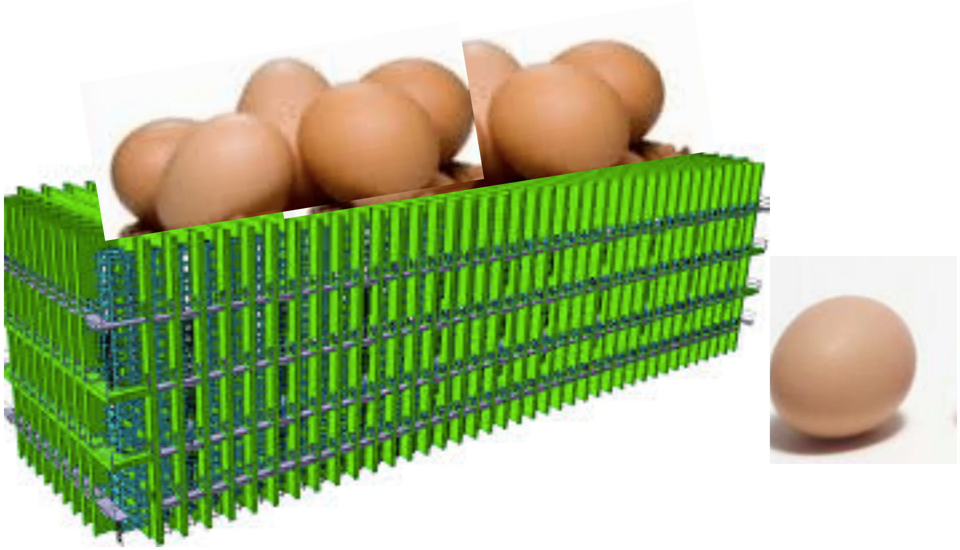


Comments

- **Significant R&D for the LAr TPC experiments remains**
- Astrophysical neutrino detectors tend to be multi-purpose (long-baseline beam targets, proton decay, NLDBD when doped, ...)
- Neutrinoless double beta decay presents daunting background challenges
  - **physics is too good to be stove-piped!**
- **Common technology goals for low-energy neutrino detection (CEvNS) and dark matter experiments**: “one person’s background is another’s signal”

Identification of Risks and Opportunities

- A lot of eggs in the DUNE basket: it's ambitious and we **must** make it work!
  - HV, purity,..
  - Photons
  - 39-Ar
  - Event reconstruction
  - Low-energy events
  - ...



- But there are opportunities beyond LArTPCs: should avoid monoculture and keep a diversified portfolio (to mix the metaphors)

Recommendations (for consideration)

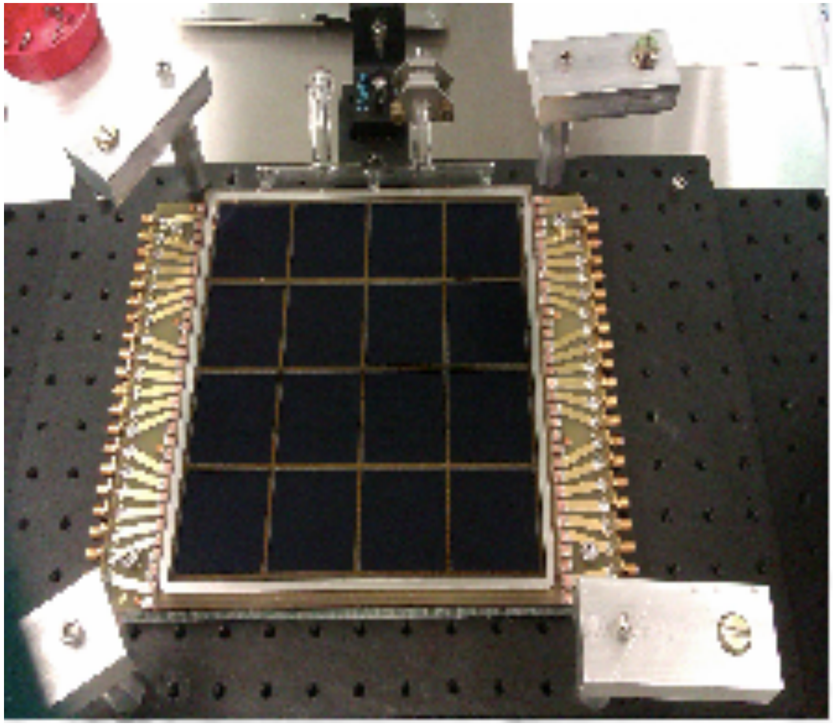
- R&D relevant for DUNE is critical
- New ideas for smaller experiments and generic technology should not be neglected
- HEP researchers with expertise for neutrinoless double beta decay should be supported: need HEP/NP connection
- Establish CF/IF connection for low-energy neutrino detection and dark matter experiments

Possible Grand Challenge Ideas?

- Lots of generic/incremental (but critical) things to go for... ~always want
  - lots of mass
  - low background
  - segmentation
  - high efficiency for energy deposition (photons, ionization,...)
  - particle ID and final state reconstruction
  - ...
- DUNE can be considered a “grand challenge”
- But here are a few specific “charismatic” items as grand challenges... where breakthroughs will be transformational (not quantified, but could do that)
  - these probably overlap with “technology” group challenges

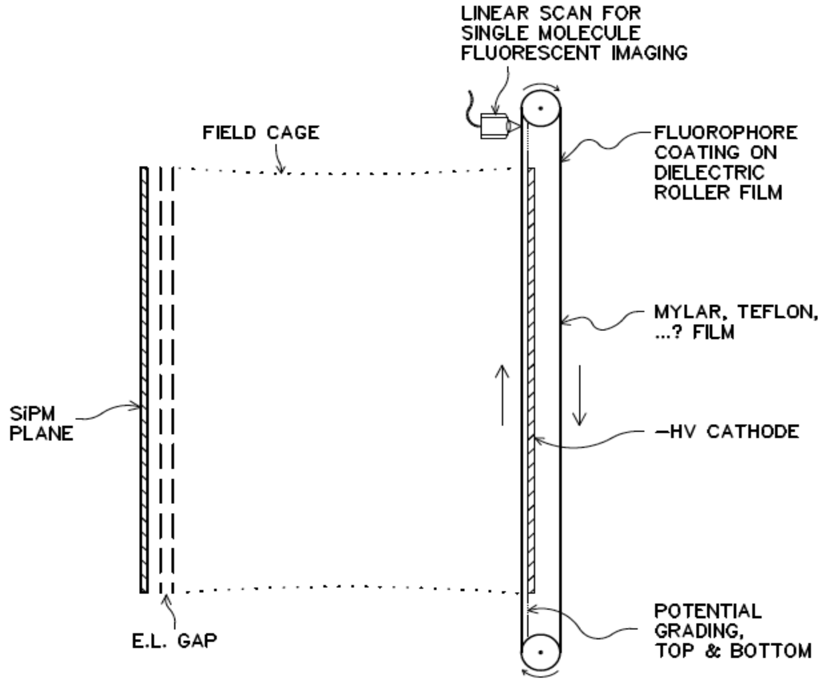
Possible Grand Challenge Ideas

- **Large-area, really cheap, efficient photosensors** would be a game-changer for large homogeneous detectors for oscillations and neutrino astrophysics



Possible Grand Challenge Ideas

- **Neutrinoless double beta decay daughter tagging**: could approach zero background



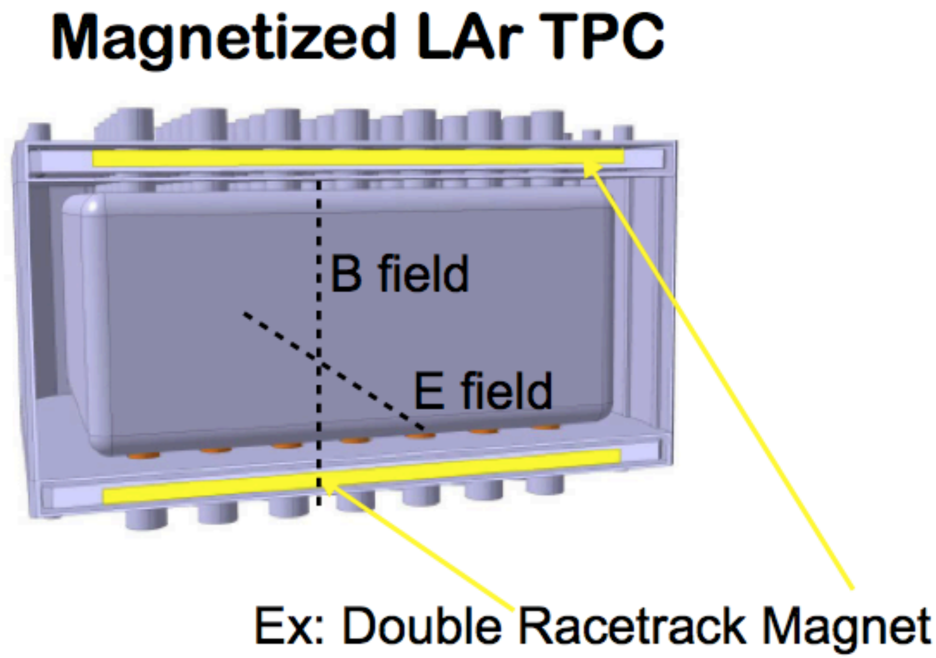
HIGH PRESSURE XENON GAS ELECTROLUMINESCENT TPC
WITH SINGLE MOLECULE FLUORESCENT IMAGING OF BARIUM DAUGHTER

Possible Grand Challenge Ideas

- **Large-mass (ton+-scale??) sub-keV-threshold nuclear recoil detectors**: key for DM as well as neutrinos (CEvNS)

Possible Grand Challenge Ideas

- **Magnetized liquid argon TPC**
  - nu vs nubar
  - momentum



O. Palamara

Conclusion

- Incremental and transformational: both shape the landscape

- Many opportunities and challenges for neutrino physics